AN OCCURRENCE OF COAL WHICH BEARS EVIDENCE OF UNUSUAL CONDITIONS ACCOMPANYING ITS DEPOSITION[1]

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It is purposed to describe an occurrence of coal which is unique in its relationships to the overlying and underlying rocks and which shows by the structures in the associated sediments that it was deposited under conditions which were peculiar. Certain of these conditions differed widely from those which were usual to the accumulation of a continuous deposit of coal over a broad area, but it appears that certain other conditions which are suggested by the occurrence may have held during the accumulation of those coals which have been formed in the more usual manner.

THE OCCURRENCE

The occurrence is in a deep cut on the B. & O. Railroad at Sommerset, Perry County, Ohio. At either end of the cut a highly fossiliferous marine limestone is exposed, but throughout most of its length the bottom of the cut is not deep enough to reach it. This limestone, about 3 feet in thickness, is probably the Lower Mercer member of the Potsville formation. It is generally present in this region 75 or 85 feet above the base of the Pennsylvanian.

Above the limestone is a bed of soft gray clay shale which is some 12 to 15 feet thick. It is overlain by a massive coarse sandstone whose thickness is estimated at 20 to 25 feet. The upper part of the shale and this sandstone are exposed throughout the cut. The contact between them is very irregular, rising and falling as much as 6 or 8 feet. In pockets at this contact, well shown for 300 yards in the deeper part of the cut, the coal under consideration is found.

Above the sandstone there is a bed of shale 1 or 2 feet thick, overlain in turn by a second coal seam. Both of these are inacces-

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sible. The upper seam is continuous and regular in thickness (perhaps 10 inches), so far as observation shows, from one end of the cut to the other.

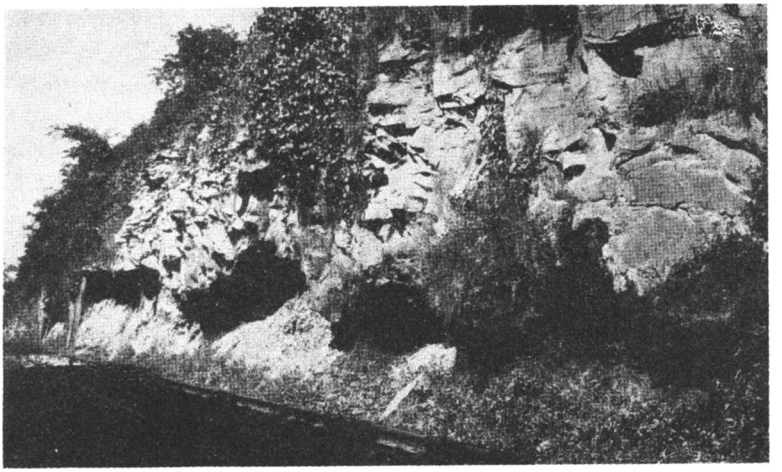

FIG. 1.—View of northwest side of the cut, showing the irregular base of the sandstone resting on soft shale. Four distinct shale crests each capped by a coal deposit (not visible) and four intervening sandstone-filled troughs with no coal are shown. The gentle inclination of the bedding (toward the observer) is wholly obscured by the irregular fracture faces of the sandstone.

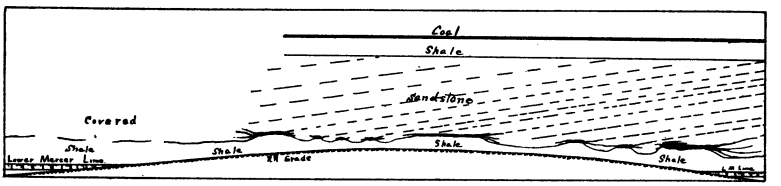

FIG. 2.—Idealized section of cut, showing relations of various members exposed. The vertical scale is much exaggerated, and the inclination of the sandstone is far too prominent. The structure near the top of the sandstone is not known. No attempt is made to represent the coal pockets at the base of the sandstone as they actually occur, although their general relations are correctly indicated. The thickness of these coal deposits is also overemphasized.

The massive sandstone and the upper coal seam can be traced for many miles in the region and seldom lose their identity. The coal seam at the base of the sandstone, on which interest centers

for the moment, if present generally, is seldom observed; the sandstone does not tend to form cliffs, and outcrops of this horizon are scarce.

The base of the sandstone which rests sharply either on the coal or on the shale when the coal is absent, rises and falls irregularly through several feet, and suggests strongly the existence of an erosion surface. This suggestion is supported especially by the distribution of the coal which is present only where the base of the sandstone is high, and disappears where it is low. It is not unusual to find coal seams overlain by a sandstone, which are thinner or wanting entirely in places because, as commonly expressed, the sandstone "cuts out" the coal. It has generally been supposed that such an interruption is due to erosion, and doubtless it is in some cases; but in the present one, this is not the correct explanation. At only one point, and that for but a few feet, is there any evidence of erosion, and even that is not conclusive in view of the irregularity found at all other points.

OCCURRENCE OF THE COAL IN POCKETS NOT DUE TO SUBSEQUENT EROSION BUT AN ORIGINAL CHARACTER

There are some 10 or 12 shale crests in the 300 yards which are clearly exposed, each with a bed of coal on the crest. In the sandstone-filled "troughs" which intervene there is no coal. The thickness of the coal, where present, varies from a fraction of an inch to 35 inches, rarely exceeding a foot. Horizontally, the coal may persist for only 2 or 3 feet on a small crest, or it may persist for 40 or 50 feet over a larger one. The sandstone troughs are of about equal width. But the coal is not truncated by the sandstone as it descends on either side of the crest. The coal seam splits and disappears on either side by interfingering with those portions of the sandstones which fill the "troughs." The seam may split abruptly into two or three thin streaks, and each of these in turn into as many or more within a few inches. Not infrequently two partings will reunite around a thick lens of sandstone.

There appears to be only one possible interpretation of the relation of the coal to the sandstone. The vegetable matter was accumulated in very limited patches, and coarse sands, sometimes

full of large and small plant fragments, were deposited simultaneously between these patches. The vegetable mud which later formed the coal was originally of about the same thickness as the intervening sands and was intertongued into them. Subsequently the vegetable mud was compressed to only a small fraction of its original thickness, but the sands were affected to a limited extent only.

AMOUNT OF REDUCTION IN THICKNESS OF ORGANIC DEPOSITS IN CHANGING TO COAL

Observations on several occurrences in the cut as to the relative amount of compression of the coal, as shown by the equivalent thickness of sandstone, give widely conflicting results.

	Thickness of Coal	Thickness of Equivalent Sandstone	Ratio of Coal to Organic Mud
1	3–4 inches	46 inches	1 to 11½ to 15
2	1¾ inches	30 inches	1 to 17
3	⅛–¼ inches	15 inches	1 to 60 to 120
4	4 inches	20 feet	1 to 60
5	5 inches	31 inches	1 to 6*

* Thin coal streaks are prominent in the sandstone in the last case.

There are, however, certain factors which explain this variation in large part or entirely, although they do not allow a precise determination of the actual reduction in volume in the process of coal formation. In certain of these occurrences, there are many thin stringers of coaly material involved in the sandstone where its thickness was measured, and these also suffered reduction of volume, so that the thickness of sandstone given does not necessarily represent the original thickness of the adjacent column of plant mud. It cannot be said that these are more important in the first two instances and help to explain the relatively smaller thickness of sandstone there found; but they do explain in part the small thickness of sandstone in No. 5. As a matter of fact, the first two seem to indicate most nearly the actual reduction in thickness of the coal. There is a yet more uncertain factor involved in the inclined bedding of the sandstones, to be discussed below.

ADJUSTMENT OF THE SURROUNDING SEDIMENTS TO THE CHANGE IN VOLUME

At the time of the compression of the coal to its present volume or near it, some adjustment in the distribution of the adjacent sediments was necessary. This was accomplished, perhaps almost entirely, by flowage in the underlying soft clay shales, which slowly bulged upward beneath the coal deposits as their bulk became less, and came to form the shale crests which are capped by the coal. This is demonstrated by the fact that where thin sandstones are present in the shales, they are distinctly arched upward in these crests (Fig. 4). The sandstones over the coal are undisturbed except where they are interbedded with thin coals which have also suffered compression. On the side of one of the shale crests and in contact with the shale, they show flowage lines similar to slickensides, caused by the upward movement of the shale. There is evidence at one point that some of the movements of readjustment were abrupt; shales with a few thin sandstone beds are turned upward at a sharp angle for several feet so that their edges rest against the nearly horizontal bottom of the overlying main bed of sandstone. The bottom of the sandstone in this case carries the impression of the upturned thin sandstone layers of the shale series. These occurrences are believed to demonstrate that the massive sandstones were not consolidated at the time of the readjustment.

EFFECT OF INCLINED BEDDING IN DETERMINING THE AMOUNT OF REDUCTION

The most remarkable feature of the entire deposit is found in the inclined bedding of the thick sandstones, and in its relation to the coal pockets. The inclination of the bedding throughout most of the cut is toward the north and northeast, and usually at a low angle, commonly from 5° to 10°. At the south end of the cut the inclination is changed for a few yards to southeast. At the north end, just at the point where the outcrops become obscured by the low gentle covered slopes of the shallower part of the cut, the sandstones appear to have been derived from the northeast. The occurrence shown in Fig. 4 is found where the material from the two directions met.

For a distance of 120 yards, where the sandstones are persistently inclined to the north-northeast, the tongues which split off from the upper part of any one coal pocket toward the source of the material (that is toward the southwest) rise on the surfaces of the inclined bedding planes. This relation is best understood by reference to the accompanying sketches. ' It is this condition which, in part, makes uncertain the figures given above as to the relative thicknesses of coal and sandstone which accumulated simultaneously. The thickness of sandstone, except in No. 4, was obtained over the sandstone "trough" adjacent to the coal and represents the maximum over that trough, perhaps 10 or 15 feet from the coal. This is about as far as the thin coal streaks can be distinctly and readily traced (except in No. 5, where they are still present at the point where measured); but the bedding planes, which are continuations of these streaks, can be followed up the inclinations to the southwest until they are 15 feet or even 20 feet above the base of the sandstone. While in the outcrop there may be no reason to suspect a continuation of the coaly matter upward along the bedding plane, slight bruising of the stone with the hammer edge not infrequently yields a black stain, even when the beds appear to be in contact with each other. This thin film of carbonaceous material, rising many feet along the bedding planes, beyond the coal laminae, makes it difficult to determine just what thickness of sandstone is to be considered as formed simultaneously with the adjacent column of coal. The thickness given in all but No. 4 is that of the sandstones, which are somewhat irregularly bedded and lensed as a result of the thin streaks of coal and their compression, but measured as nearly as possible where there is no appreciable thickness of coal in the measurement. If measured farther away from the coal pocket, the thickness would be increasingly greater, but the sandstones, although carrying traces of carbonaceous matter on the bedding planes, would be regularly inclined and undisturbed by the compression, because the coaly matter was too thin to cause any appreciable readjustment in them. Furthermore, the thickness, when measured at the point usually selected, agrees fairly well with the heights of the shale crests above the base of the sandstone troughs; these are believed to be a rough

index of the amount of compression which has taken place in the coal.

However, the actual original thickness of the organic mud, and the exact amount of compression it has suffered, are only incidental to the subject under consideration, and are not at all essential to the interpretation of the associated structures.

POCKETS OF COAL NOT ACCUMULATED SIMULTANEOUSLY BUT SUCCESSIVELY

When one of the coal pockets splits into a number of thin layers, the layers spread out vertically through several feet of sandstones. These may or may not reunite to form the next adjoining coal pocket. More commonly they do not. The topmost coal parting on the side *toward* the source of the sands commonly rises with the rise of the bedding planes entirely above the coal pockets in that direction. On the other hand, the topmost parting on the side *away from* the source of the sands usually passes into the middle of the next pocket in that direction, or into its lower part or even entirely below the lowest stringer which comes from it. This is due to the gentle inclination of the sandstones.

This signifies an unusual method for the accumulation of the coal, if it is correctly interpreted. If the topmost and bottommost stringers from two coal pockets are continuous from one to the other, no matter how far vertically they may diverge in the intervening sandstones, they are held to have been deposited simultaneously. On the other hand, if the top of one passes into the middle of the next one, the upper half of the latter is held to have accumulated after the former had ceased to form, or if the top stringer from one passes entirely beneath the bottom of the next one, the latter is held to have been wholly deposited subsequent to the former. These are the premises on which the conclusions rest.

When all of the coal pockets (nine in number) are considered in that portion of the cut where outcrops are entirely unobstructed and where the source of the material is persistently from the southwest, it is apparent that the one at the southwest end is the oldest, that is, the one nearest the source of the inclined sands. Further-

more, the deposition of each one of the nine was either begun later than that of its neighbor to the southwest, and was completed later,

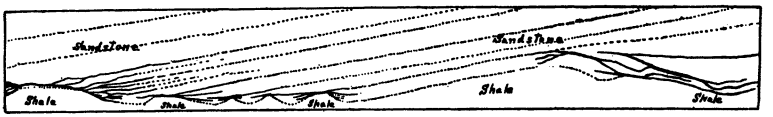

FIG. 3.—Generalized sketch of five of the crests and a portion of another, showing the relation of the coal deposits to the inclined bedding of the sandstones. Solid black lines, coal; dotted lines, bedding planes, usually with a black stain.

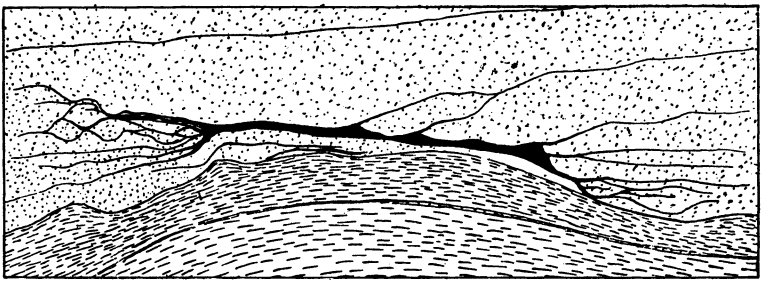

FIG. 4.—An occurrence of coal on one of the crests. In this case the sands were derived from both directions. Drawn correctly to scale from photographs and sketches.

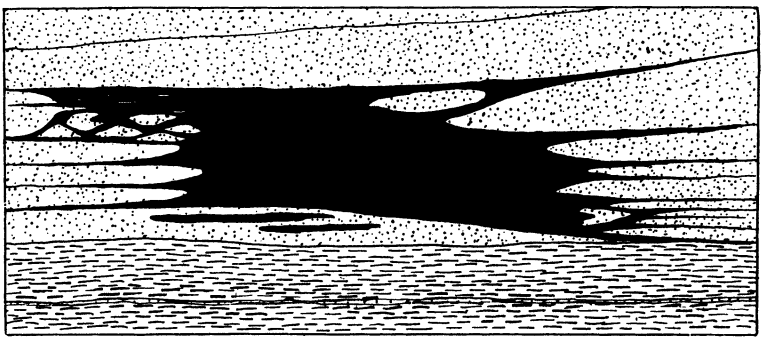

FIG. 5.—Ideal representation of the occurrence shown in Fig. 4, before compression.

or was begun entirely after this neighbor had been formed. Each pocket was formed at the toe of the advancing sand deposit, to be later covered and checked in its growth while a new deposit of

organic mud formed a few feet beyond where the edge of the sand had taken its new stand. The only exception to this statement is found in two adjacent beds which seem to have been formed simultaneously.

The coal deposits, although limited in cross-section, all have a lineal extent which is obliquely across the railroad cut and roughly parallel to the strike of the inclined beds of sandstone. This is so persistent that crests, troughs, sharp flexures, or even an unusually prominent split in a seam, features which may be only a few inches or two or three feet at most in width, can be recognized on both walls of the cut, and in the same succession. These are so regularly persistent that if the sandstones could be entirely removed over a wide area, the shale crests would appear as a series of roughly parallel ridges. The directions of ten of these features, selected because of their prominence, have been measured and all trend from northwest to southeast, although they vary through 40°. This directly supports the idea that they were accumulated along the edge of the sandstones as they advanced, delta-like, from the southwest.

There is but one feature for which no explanation is offered and which is not wholly in accord with the interpretation. In every case, there were sands accumulating immediately adjacent to the coal deposits and simultaneously on the side away from the source of the inclined sands. They are never thick and always have extended only a few feet beyond the deposit of coal mud. These muds were interfingered into them. What may be their significance, if any, is not known.

SUMMARY OF THE KNOWN FEATURES OF THE OCCURRENCE

To summarize the formation of the coal: It appears that it was not formed as a continuous deposit and subsequently cut up by erosion, nor were the pockets formed simultaneously in their present separated condition. It appears that the pockets were formed successively one after the other at the edge of the accumulating mass of inclined sand; that the vegetable mud accumulated to a thickness commonly of three or five feet (possibly 40 feet in the case of the 35-inch coal, although this seems excessive); that these

accumulations extended for considerable distances along the front of the sand deposit but only to a width of a few feet, and were intertongued with and accumulated simultaneously with the adjacent sandstones; that each deposit of coal mud in course of time was covered and its growth checked by the advancing sands while a new one formed a few feet beyond at the new edge of the sand, to be later covered in turn; that after the whole series had accumulated, the organic mud was compressed in the process of coal formation until its thickness was only about one-fifteenth its original thickness, and that the readjustment necessitated in the surrounding sediments by such local contraction was accommodated largely by the soft shales underlying the coal and sandstone.

It is worth while, also, to call attention to the general conditions at the time of formation of the deposit. The marine limestone, a few feet below the coal, is known to persist over two or three adjacent counties, and, if properly identified as the Lower Mercer, it extends over much of eastern Ohio and northwestern Pennsylvania. It marks a period of cessation from deposition of the sandstones and shales, with coals, which constitute most of the Coal-measures, and which, when fossiliferous at all, are only plant-bearing; it marks the prevalence of marine conditions over a large part of the northern Appalachian coal basin. The uniform thickness and character of this limestone bed indicate that it is the result of an abrupt subsidence which dropped the entire area far enough below sea-level to give open marine conditions. The phenomena caused by transgression and regression, resultant on a slow subsidence from above sea-level, appear to be entirely lacking. That open marine conditions, probably in shallow water, prevailed, is shown by the diversity of marine life forms present and the abundance of species and individuals which is commonly found, in central Ohio at least, at this horizon.

The limestone is succeeded abruptly in central Ohio by gray argillaceous shales between 10 and 20 feet in thickness—the shale below the coal seam under discussion. These quite commonly carry a marine fauna in their lower part. How rich this fauna is, is shown by the presence of 57 species from the shale at this locality in the collection of the writer's father, Mr. Eber Hyde. This

fauna is entirely absent from the upper part of the shale and it is evident that the typical marine conditions were excluded during the formation of the upper part, although there is no break discernible in the sediment and no evidence of shoaling in the shales.

The formation of the sandstones and of the coal bed marks the first resumption of typical Coal-measures sedimentation of the so-called continental type. The whole series suggests abrupt shoaling from shallow marine conditions and the dumping of sands, delta-like, into a shallow body of water, perhaps yet brackish but in which no marine organisms were living.[1]

WERE THE POCKETS FORMED BY GROWTH IN POSITION OR BY FLOATATION OF ORGANIC MATERIAL?

In what has been considered thus far, there is seemingly little room for speculation. The structures are distinct and the various relationships can readily be determined. Apparently, there is not a single conflicting feature, although some may be little understood. The interpretation given seems the only one possible, although certain conditions of coal accumulation are suggested thereby which are unusual, to say the least. However, these conditions probably have not obtained over any very great area and during the accumulation of none of the important seams. Certain other conditions seem to follow as a result of this interpretation, but in what remains to be said regarding these, there is less of certainty than in what has preceded.

Perhaps the most remarkable feature connected with the occurrence is the extreme localization of the deposits of organic mud. It is very curious that it should have accumulated along the foot of the sand slopes to the depth demanded, 5 feet more or less, but

[1] In this connection must be noted the finding in this railroad cut of a piece of coal with a well-preserved nautiloid shell in it, as yet, unidentified. The piece is entirely of coal and the fossil is preserved as an impression, the shell being wanting entirely. The piece was loose and it cannot be affirmed that it came from one of the coal pockets in the cut, as some coal is hauled through it from the Hocking Valley field. It is undoubtedly a case of a marine organism preserved in coal, but its source must be considered unknown, with a fair chance of its having been native to the cut.

should never, at any stage, extend more than a few yards outward from these slopes. This did not happen once only, but a number of times, and, furthermore, every time that there was any such accumulation, it was very limited. At first it was thought that the many thin stringers of pure coal ramifying through the sandstones with no evidence of "bottom clays" or old soil beds were evidence that the organic muds had been carried in suspension and dropped at the points where the coal is now found; if such had been the case, it is inconceivable that the mud would not have spread at each stage of mud deposition farther to the northeastward beyond the limit which was clearly set for it. What this limiting factor may have been is not apparent from the deposits themselves. As indicated earlier, sand at times accumulated to a small thickness on the side away from its apparent source, and plant muds were interfingered to some extent with this sand; but the coals disappear mostly by thinning within a few yards.

The best explanation for this narrow strip of organic mud extending along the margin of the inclined sands seems to be that it grew at the point where it is found, and that, at times, the growing plant beds spread out for short distances over the sands accumulating near by and thus became interbedded with them. The growing plants, on this assumption, were confined to the border of a shallow body of water and did not spread more than a few yards from the edge, although why they should not have spread over much more of the bottom which must have been just as shallow is not apparent. The water probably was not nearly of a depth equal to the thickness of the entire sandstone bed, since the coal is only interfingered with its base. In this connection, what the significance of the trace of black shale or coal extending up the bedding planes may be, cannot be said. It seems quite possible that the level of the water was a fluctuating one, standing low during stages of plant growth, and high at times of flood when the sands were brought in in large quantity.

It is not intended to imply that the rates of accumulation of both sands and muds, in so far as they accumulated simultaneously, were equal. On the contrary, the sand was probably dumped in

at intervals, when it would accumulate to a considerable thickness— several inches— in a short time. At these intervals it might bury a tongue of the plant mat which had spread out over preceding sands, but was often insufficient to cover the whole, and received a check, possibly from the plants themselves, that held it back of the main bed. As soon as an accumulation of sand buried the plants entirely at any one point, growth recommenced at the new margin. That there were frequently a number of such attacks by the sand which only covered thin extensions of the plant bed, is shown by the presence not infrequently of three or four or more beds of sandstone interbedded at the side of the coal, but not encroaching to any extent on its main body. Had the accumulation of the coal mud been due to deposition from suspension, it seems highly improbable that the sandstone incursions would have respected the unity of the deposit to any such degree.

The coal, too, in the main bodies and in most of the stringers is remarkably pure (ocular inspection only). Occasionally a thin clay parting is to be observed in undisturbed portions which is undoubtedly original in the coal, but these are so far absent, although to be expected in such accumulations as to negative further the suspension theory for the origin of the coal.

There is, however, no suggestion of a basal clay beneath the many thin stringers of coal which are found in the sandstone. Nor are there any of the characteristics of a basal clay or fire cla to be observed in the soft gray shale which underlies the coal deposits where they are thickest and without sandstone lenses, although these have usually been considered characteristic of growth of vegetation in place. However, the marginal swamp theory and the accumulation of the vegetable mud by growth in position is apparently a much more satisfactory explanation of the deposit as a whole than the flotation theory and is believed to be the correct one in this case. To say the least, the whole suggests very strongly that it may be possible for coal to be formed by growth in position, the time-honored conception of coal formation, without the development of an underclay full of root impressions, the presence of which has always been one of the chief facts in evidence to support this conception.

WHEN WERE THE DEPOSITS COMPRESSED TO APPROXIMATELY THEIR PRESENT THICKNESS?

There is yet another feature to be considered, the time when the reduction in volume of the coal mud occurred. Evidence has already been cited to show that this occurred while the sandstones were yet unconsolidated. As has been repeated, the accommodation of the surrounding sediments to this shrinkage was, in large part, by movement in the underlying shale. There was also some readjustment in the lower part of the sandstones, as shown by the irregular lenses between the coal stringers. But whether there was any very appreciable movement in the main body of the sandstone overlying the coal is not known. There must surely have been some. In one of the pockets, there are 12 to 14 inches of coal along a width of 60 feet, in another, 35 inches of coal are found in a rapidly pinching lens. Both of these cap unusually high shale crests, but it seems impossible, in these instances, that the thickness of vegetable mud necessary to form them, at the very least 15 feet, could have been compressed to its present state without allowing the overlying sandstones to settle slightly and irregularly. But the shale bed and coal which follow next above the sandstone are evenly horizontal and continuous and show no evidence of any such irregularity. This coal was formed as a sheet extending continuously over a wide area, and in a manner differing radically in detail from the one at the base of the sandstone. Its regularity in the cut is such as to suggest that equilibrium had been quite fully established in the underlying sediments before it was laid down although proof positive to this effect is not at hand. In other words, it is probable from the evidence furnished by this occurrence that some of the organic deposits which later formed the soft coals, perhaps all, were compressed nearly to their present volume very soon after accumulation. This loss of volume was probably chiefly due to the pressing out of the large quantities of water which must have been inclosed in the deposit at the time of accumulation. The loss of the volatile gases which marked the ultimate change to coal must have been accomplished more slowly, although it seems possible that a part of this, too, occurred at the time of this first loss. The not infrequent finding of coal pebbles

in Coal-measures rocks in such condition that they must have been coal at the time of their erosion—this too with no evidence of deep erosion of previously formed Coal-measures at any time during the accumulation of the whole—shows conclusively that the organic beds, within very short periods after their accumulation, had suffered most of the changes which resulted in the formation of coal from them.